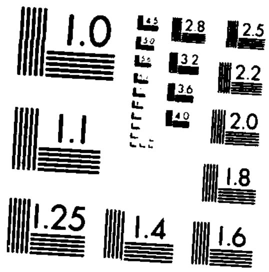


MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS 1963 A

MRL-R-1068 AR-005-148

(4)

DTIC FILE COPY

DEPARTMENT OF DEFENCE

DEFENCE SCIENCE AND TECHNOLOGY ORGANISATION

MATERIALS RESEARCH LABORATORIES

MELBOURNE, VICTORIA

REPORT

MRL-R-1068

PERFORMANCE OF A DIGITAL REAL TIME RADIOGRAPHIC IMAGING SYSTEM

M.J. Chung

Approved for Public Release

DSTO MRL
MARIBYRNONG

DEPARTMENT OF DEFENCE

MATERIALS RESEARCH LABORATORIES

REPORT

MRL-R-1068

PERFORMANCE OF A DIGITAL REAL TIME RADIOGRAPHIC IMAGING SYSTEM

M.J. Chung

ABSTRACT

This report examines the radiographic and electro-optical characteristics of a digital, real-time radiographic imaging system. It was found that;

a. for optimum X-ray magnifications the television camera tube in the system has a significant effect on image quality and

b. large variations in X-ray tube voltage may be tolerated before image degradation prevents successful computer image processing.

This work forms part of a study on a computer-aided inspection process.

Approved for Public Release

POSTAL ADDRESS: Director, Materials Research Laboratories
P.O. Box 50, Ascot Vale, Victoria 3032, Australia

CONTENTS

PERFORMANCE OF A DIGITAL REAL TIME RADIOGRAPHIC IMAGING SYSTEM

1. INTRODUCTION

Conventional film radiography produces images of high resolution and large contrast range that are suitable for visual inspection. However, in munitions production where large numbers of items are to be inspected, film radiography is expensive, time consuming and subject to operator fatigue and error. Such errors in the inspection of munitions can result in hazardous situations that could result in malfunctions during storage and use.

Real-time radiographic techniques have been available for some time [1] but the image quality produced by this method has been inferior to that of film radiography. However, improvements in image intensifiers together with the use of digital image processing techniques now provide good quality images which give an attractive alternative to the film radiographic process. These new methods have the potential to avoid many of the disadvantages of the present inspection process and may be readily adapted to automatic inspection with the consequent reduction in inspection errors.

This report examines the radiographic and electro-optical characteristics of a digital real-time radiographic imaging system which has been successfully applied to the inspection of fuze assemblies in the laboratory. The images produced are in a form suitable for computer processing and will be the subject of a later report.

2. BACKGROUND

A block diagram of the equipment used to produce digitized real-time radiographic images is shown in Figure 1. The system consists of a continuous X-ray source, a manipulator to accurately position the object under

examination, an X-ray image intensifier with collimating lens to convert the X-ray images to visual images and a television camera with lens to view the image. The output from the television camera is digitized and stored on a floppy disk in a format suitable for processing by computer.

The final image produced by this system is affected by the characteristics of both the X-ray and the electro-optical imaging sections. These characteristics, together with system noise, reduce the number of distinguishable grey levels in the image [2]. In this report, the X-ray imaging section in Figure 1 is taken as the X-ray source and X-ray sensitive input screen of the image intensifier whilst the electro-optical imaging section comprises the image intensifier, lens and television camera.

Image quality from this real-time radiographic system may be defined in terms of radiographic efficiency and spatial resolution. Radiographic efficiency is the conventional method [3] for describing the ability to distinguish between contrast levels and is defined as the ratio of the smallest perceptible material thickness increment in the object to the total thickness. The efficiency may be measured with DIN IQI gauges [3] of a material similar to that of the object. The spatial resolution of the system is its ability to discriminate between near-by features which have the same contrast in the image plane. It may be measured in terms of the Contrast Transfer Function (CTF) or the Modulation Transfer Function (MTF) [1,4]. The factors affecting image quality are discussed below in more detail under the headings of "X-ray Imaging" and "Electro-optical Imaging".

2.1 X-ray Imaging

The images produced at the input of the image intensifer by the radiographic system shown in Figure 1 are affected by several factors. Spatial resolution and contrast are functions of the characteristics of the X-ray tube, the material coating on the input screen of the image intensifier and the relative positions of the X-ray source, object and image plane.

By careful adjustment of the X-ray intensity and the imaging geometry together with the use of material filters and masks to isolate the feature under examination, suitable images can be obtained for analysis. From Figure 2A, the X-ray projected magnification M_x for a point source is given by

$$\begin{aligned} M_x &= \frac{c}{d} \\ &= \frac{a+b}{a} \qquad (1) \end{aligned}$$

and, from Figure 2B, the penumbral image width, usually termed the geometric unsharpness U_g is given by

$$U_g = \frac{b}{a}\phi$$

$$= \phi (M_x - 1) \qquad (2)$$

where 'a' is the source-object distance, b is the object-image plane distance and ϕ is the physical size of the X-ray source. The graininess and thickness of the fluorescent screen of the image intensifier also contributes to the image unsharpness [1].

The total unsharpness U_t of the system is the combination of the screen unsharpness U_s and geometrical unsharpness U_g. It has been found empirically that for normal film radiographs U_t is given by [3]

$$U_t = (U_s^3 + U_g^3)^{1/3} . \qquad (3)$$

For satisfactory discrimination of a feature, its width at the X-ray image plane should be much greater than the total unsharpness, i.e.

$$c >> U_t$$

or $$d >> \frac{U_t}{M_x} . \qquad (4)$$

The screen unsharpness of an image intensifier is generally unknown. However, an optimum range of magnifications can be found empirically [3] for which the minimum detectable feature width does not vary significantly with magnification.

2.2 Feature Size

Estimates of feature size must sometimes be made from a radiograph and one method is to place a calibrated scale near the object. The use of a scale in real-time radiography is not always convenient and a method to estimate feature size in terms of television lines is necessary. It can be shown (Appendix A) that the feature size at the object in both horizontal and vertical direction in terms of television lines for a 4:3 aspect ratio television system may be estimated by:

Feature Size = 0.8 K mm per television line

$$\text{where } K = \frac{D}{FM_L M_I M_x}$$

and F is the resolution of the television camera tube in lines, D is the diameter of the television camera tube in mm and M_L, M_I and M_x are the magnification of the lens, image intensifier and X-ray system respectively.

For a typical real-time radiographic system with parameters as

described in Appendix A, the horizontal and vertical feature size is 0.11 mm per television line. A similar analysis has been made for 1:1 aspect ratio television system and is shown in Appendix A.

2.3 Electro-Optical Imaging

For an imaging system with a regular grid pattern in the object plane, it is found that the contrast of the image of the grid decreases with increasing spatial frequency [4]. A measure of the variation in contrast of a spatial square-wave input to the system is the CTF. For the radiographic system shown in Figure 1, the variation in contrast may be measured in terms of voltage from the television camera video output. The CTF may be calculated from the following equation [5]:

$$CTF\ (f) = \frac{V_{max}\ (f) - V_{min}\ (f)}{V_{max}\ (f) + V_{min}\ (f)} \qquad (5)$$

where $V_{max}(f)$ and $V_{min}(f)$ may be measured by the oscilloscope and are the maximum and minimum signal levels at spatial frequency f.

The MTF is a measure of the variation in contrast for a sinusoidal spatial input to the system. Due to difficulties in obtaining a sinusoidal variation in contrast at the input of the system, the MTF may be calculated from the measurements of the CTF (f) by the following equation [6]:

$$MTF\ (f) = \frac{\pi}{4}\ [\frac{CTF(f)}{1} + \frac{CTF(3f)}{3} - \frac{CTF(5f)}{5} + \frac{CTF(7f)}{7}] \qquad (6)$$

where CTF(f) is given by (5) and the odd harmonics of CTF(f) may be obtained from a plot of CTF(f) against f.

2.4 Digital Imaging

The digitizer (Figure 1) converts the video signal into binary information suitable for image processing. The horizontal resolution is determined by the frequency of the analogue-to-digital converter at the input of the digitizer and the vertical resolution is determined by the vertical raster of the television system. The grey scale resolution is determined by the quantization of the black to white signal level of the video signal from the television camera. In priciple, a digitizer with a M bit word can quantize the composite video signal into 2^M discrete grey levels. The resulting image consists of a rectangular array of discrete binary elements.

Factors affecting the quality of the digital image are system linearity, image contrast and image noise.

The *linearity of the system* determines the uniformity of the discrete grey levels. Non-linearities will have the effect of compressing

some levels and expanding others to give a hard appearance for part of the image and a softening elsewhere. System linearity may be determined by varying the X-ray intensity at the image intensifier by use of various thicknesses of object material. The intensity I of X-rays passing through material of X-ray linear attenuation coefficient α and thickness t is given by [3]:

$$I = I_o e^{-\alpha t}, \tag{7}$$

where I_o is the intensity of the incident X-rays and remains constant.

The contrast of an image produced by the image intensifier is determined by the X-ray voltage and current and these may be adjusted accordingly. This image is converted into video voltage levels by the television camera, these levels being a function of image contrast. Noise in the electro-optical system which is comparable to the difference between adjacent grey levels would 'mask' individual levels and reduce the number available for image definition thus degrading the image [2].

The signal-to-noise ratio of images may be improved by electronic filtering thus increasing the number of observable grey levels and improving contrast. This can be done by averaging successive TV frames or by exponential smoothing [7].

3. MEASUREMENTS AND DISCUSSION

3.1 Equipment

Various configurations of real-time radiographic systems were assembled with equipment which is commercially available and detailed in Appendix B.

The system configurations used are described below in Table 1.

TABLE 1

System	Nominal Operating Voltage of X-Ray Tube kV	Input Field Diameter of Image Intensifier cm	Optical Components	Television Camera Tube
I	160	23	Zoom lens	1" Chalnicon
II	320	32	Macro lens plus extensions	1" Chalnicon
III	160	23	Zoom lens	1" Plumbicon
IV	320	32	Macro Lens plus extensions	1" Plumbicon

The image intensifier, television camera and their focussing devices could be remotely controlled from outside the X-ray exposure room. The manipulator was constructed at MRL and gave lateral and rotational control over the fuze assemblies under investigation and these could be repositioned to within 0.1 mm. This repositioning ability is of the same order as the expected minimum feature size and is consistant with the performance [8] of many robotic arms of the type that might be used in later development. Lead masks and movable lead shields were incorporated within the manipulator to define the X-ray beam and to screen unwanted features in the fuze. These precautions reduced scattered radiation and enabled particulars features to be high lighted.

3.2 X-ray Magnification and Radiographic Efficiency

To determine the optimum X-ray magnification for minimum system unsharpness, the minimum thickness of wire of a DIN IQI Iron gauge observable through a flat diecast metal plate was measured for various X-ray magnifications and tube voltages. These measurements were carried out for both the 160 kV and 320 kV tubes and for each field size (magnification) of the image intensifier. The results show that for all image intensifier settings, the minimum wire thickness detectable through a diecast plate remains nearly constant over an X-ray magnification range of 1.2 to 1.5.

The radiographic efficiencies of the Systems I and II were calculated from the measurements of the minimum detectable thickness of wire of DIN IQI Aluminium and DIN IQI Iron gauges for several thicknesses of aluminium and steel plates. The results are plotted in Figure 3. The results show that System I is able to detect variations in contrast of an image which is represented by a thickness of 0.4 mm through 15 mm of aluminium and a thickness of 0.3 mm through 5 mm of steel at 130 kV. Similarly, System

II may detect contrast variations represented by 0.8 mm through 20 mm of aluminium and 0.6 mm through 5 mm of steel at 240 kV.

3.3 Electro-Optical Response

The responses of the four systems were measured with a Tektronix 468 digital oscilloscope and recorded on a digital plotter. A sample of these results is given in Figure 4 which shows the modulation of the video signal due to a copper line pair gauge. The background level is the video signal level produced by the surrounding edges of the copper gauge and the modulation is measured with respect to this level. The measurements of $V_{max}(f)$ and $V_{min}(f)$ used in the calculation of the CTF(f) were made using the average of 32 sweeps of the Tektronix CRO.

The CTF's for the Systems I and II are plotted in Figures 5A and 5B. For these systems, the component introducing most image degradation is expected to be either the image intensifier or the television cameras. Interchanging the television cameras resulted in a greater variation in the resultant CTF than did interchanging the intensifiers. The response of the Systems III and IV are also shown in Figures 5C and D. Comparison between Figures 5A, B, C and D show a reduction of 40% in system CTF occurs when the television camera with the plumbicon tube is used. The limiting CTF for the eye is generally taken as 3% [6], and the response of all of the systems approaches this limit at spatial frequencies of 2.0 to 2.5 line pairs per mm. The Modulation Transfer Function of the electro-optical system may be calculated from these results, using equation (6).

The linearity of System I was measured by attenuating the X-ray intensity with different thicknesses of copper plate. The normalized X-ray intensity I/Io may be calculated from equation (7). The relevant log-log plot is shown in Figure 6. A linear regression curve of best fit shows that the γ (slope of log-log plot) for the system is 3.0 which is greater than the adjustable range available (0.5 to 1.0) of γ for television cameras. Linearity corrections to the digital image would need to be carried out by computer processing.

The effect of X-ray tube voltage on image contrast for System I was determined from digitized images at different X-ray voltage levels. The number of grey levels present was measured by means of a grey level histogram. The results are given in Figure 7 which shows that a change in X-ray voltage from 80 kV to 135 kV corresponds to an increase in grey levels from 40 to 167.

The reduction in image noise due to electronic logarithmic filtering [7] is shown in Figure 8 which plots the intensity variation along a line in a typical image. An increase in signal-to-noise ratio of 13db can be achieved by such filtering. This corresponds to an increase in grey levels from 68 discrete grey levels in a 'hard' image to 208 continuous grey levels in the filtered image. The increase in grey levels of an image is accompanied by an observed increase in image quality. This increase in image quality enhances visual inspection of fuzes but is accompanied by an increase of up to one minute in the time taken to produce a digital image. For the

filters [7] used in this work, the time required increased from 20 s to 1 minute.

4. SUMMARY

The optimum X-ray Magnifications for the 150kV and 320kV systems examined were found to be 1.5 and 1.2 respectively. The radiographic efficiencies of System I and II have been determined for steel and aluminium for several X-ray tube voltages. The Contrast Transfer Functions for the four systems have been measured up to a spatial frequency of 3.0 line pairs per mm. Careful selection of television cameras will improve the Contrast Transfer Functions of the system by up to 40% for midband spatial frequencies whilst the limit of visual resolution with these systems is expected to be 2.0 - 2.5 line pairs per mm. Measurements have shown System I to be non-linear and it is expected that other radiographic systems will have a similar characteristic. A method has been described to determine the feature size at the object plane in terms of TV lines at the monitor.

Day-to-day variations of 5 kV in X-ray tube voltages would not be expected to have a significant effect on image quality. Electronic filtering improves image quality but increases the time taken to produce a digital image.

5. ACKNOWLEDGEMENTS

The author wishes to thank Mr G. Cooke for the help in constructing the manipulator and Mr P. Star for his assistance in carrying out measurements described in this paper.

6. REFERENCES

1. Bossi, R., Oien, C., and Mengers, P. (1983) "The Non-destructive Testing Handbook. Real Time Radiography". American Society for Non-destructive Testing. Columbus, Ohio.

2. Castleman, K.R. (1979). "Digital Image Processing", Prentice-Hall, New Jersey.

3. McMaster, R. (Editor) (1959). "Non-destructive Testing Handbook." The Ronald Press Company, New York.

4. Lucien, M., Biberman, M. and Nudelman, S. (Editors) (1971). "Photoelectronic Imaging Devices", Vol. 1, Plenum Press, New York.

5. Lucien, M., and Nudelman, S. (Editors) (1971). "Photoelectric Imaging Devices", Vol. 2, Plenum Press, New York.

6. RCA Electro-Optics Handbook (1974) Technical Series EOH-11.

7. Bruggemann, H. "Temporal Filtering using Pixel Incrementing", SMPTE Journal, August 1981.

8. Exhibitors "ASEA Pty Ltd", "HNI Perkins", "Cybernetics Control Pty Ltd" at "National Conference and exhibition on Robotics", Melbourne, August 1984.

9. Australian Post Office, Technical Training Publication, (1965) "Introduction to Television", ETP 0307.

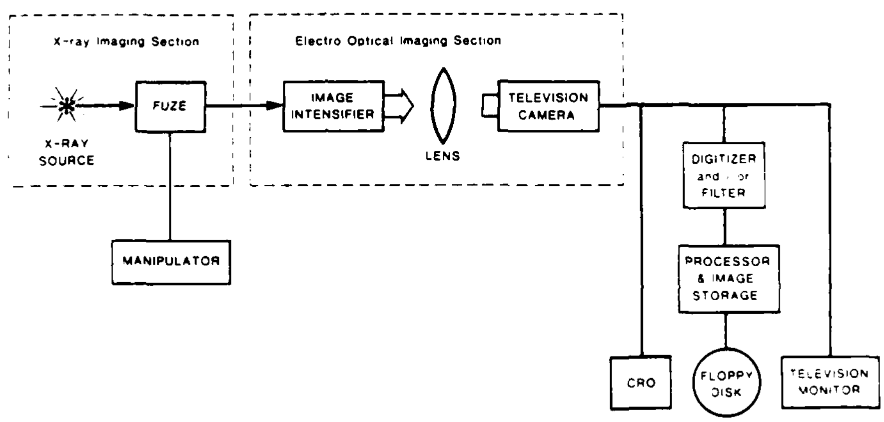


FIGURE 1 Digital Real-time Radiographic Imaging System.

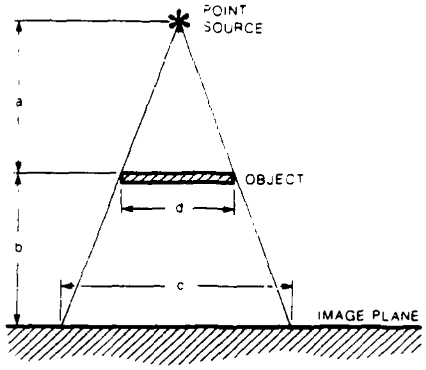


FIGURE 2A Geometric imaging using X-rays, from a point source

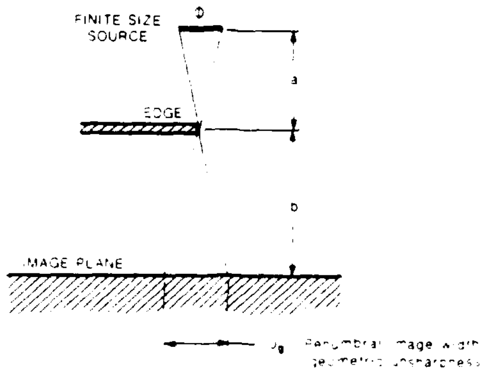
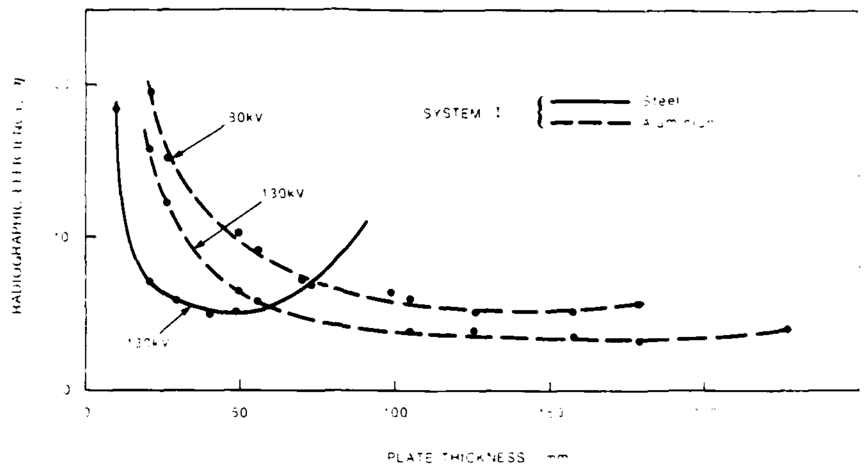


FIGURE 2B Geometric unsharpness of an edge due to finite size source.



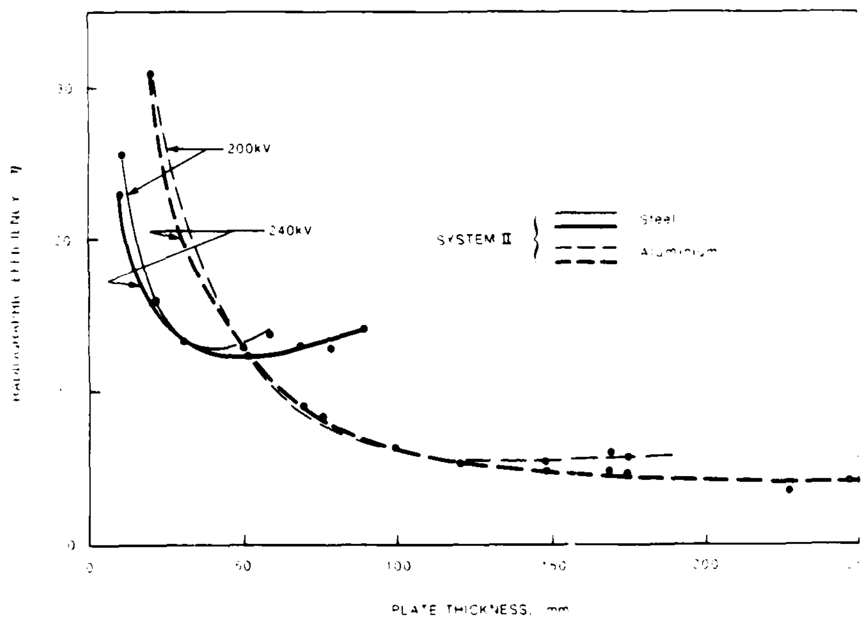


FIGURE 3 Radiographic efficiency of System I and II for steel and aluminium for various X-ray tube voltages.

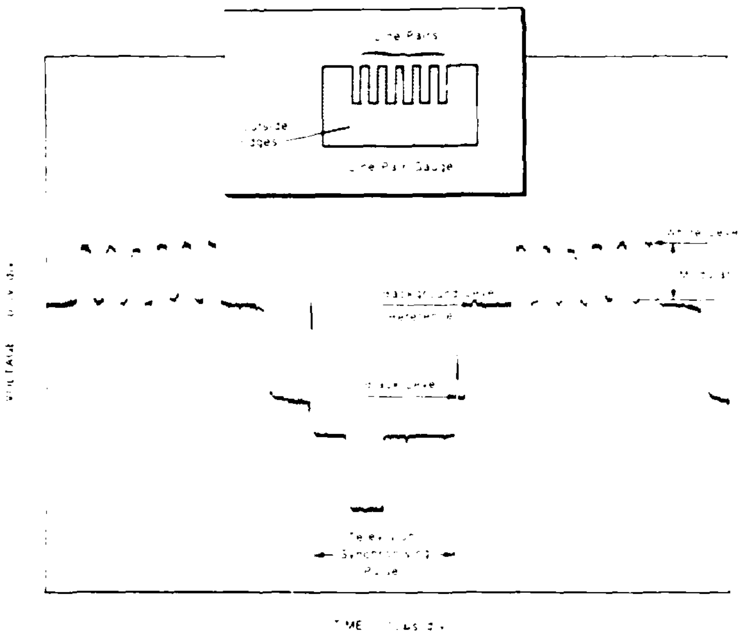


FIGURE 4 Composite video signal showing systems response to a line pair gauge. Insert: Line pair gauge.

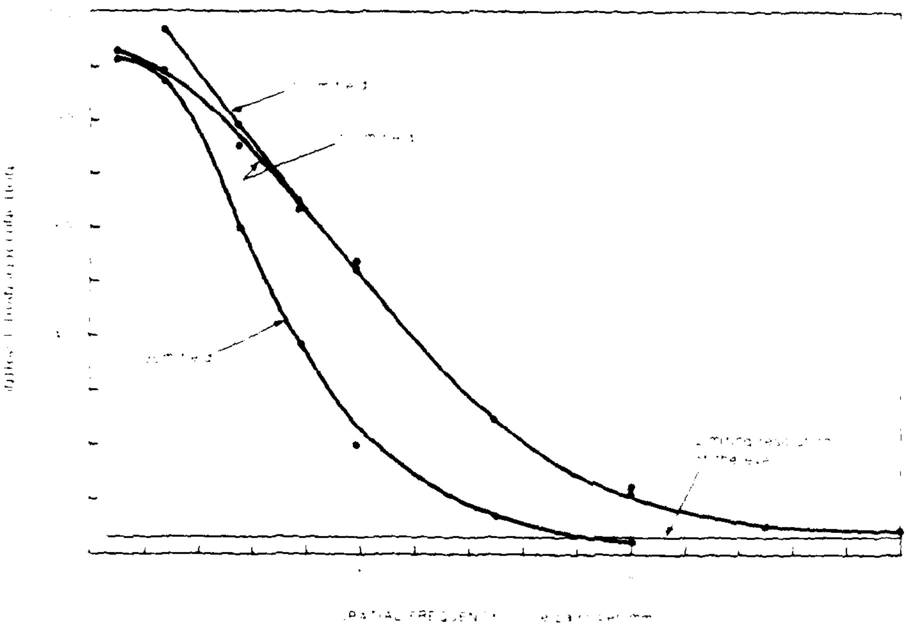


FIGURE 5A Contrast Transfer Function of System I.

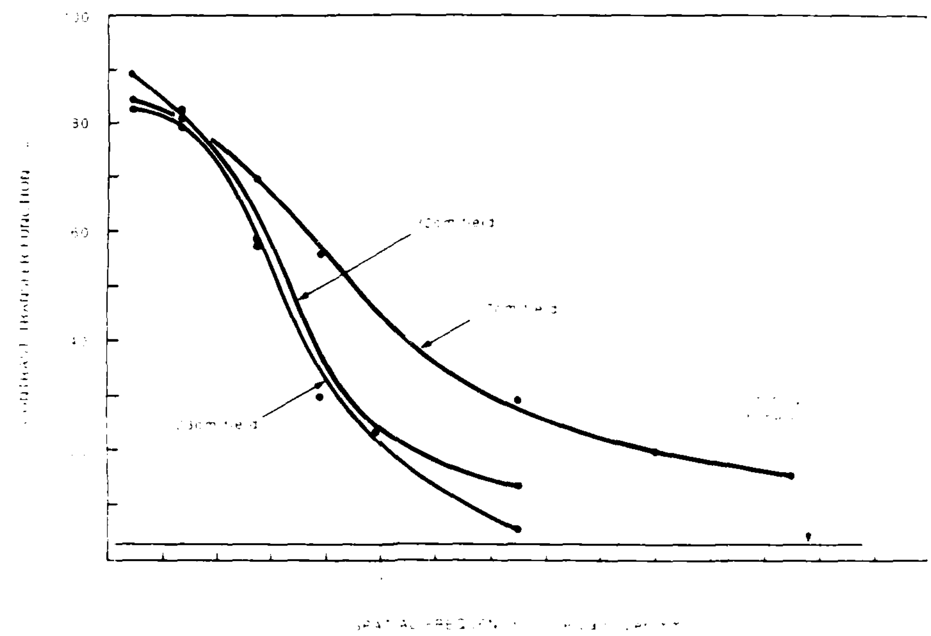


FIGURE 5B Contrast Transfer Function of System II.

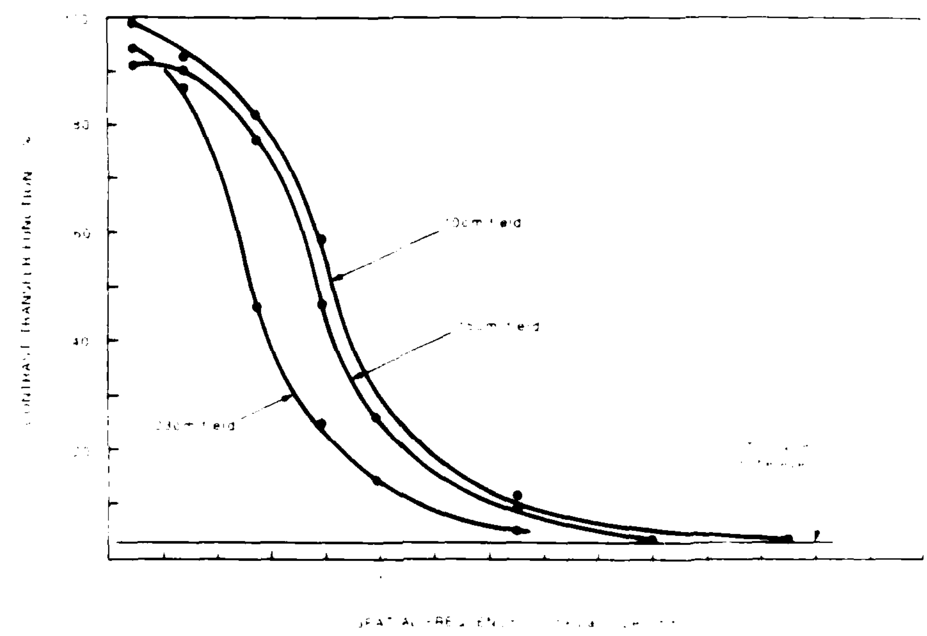


FIGURE 5C Contrast Transfer Function of System III.

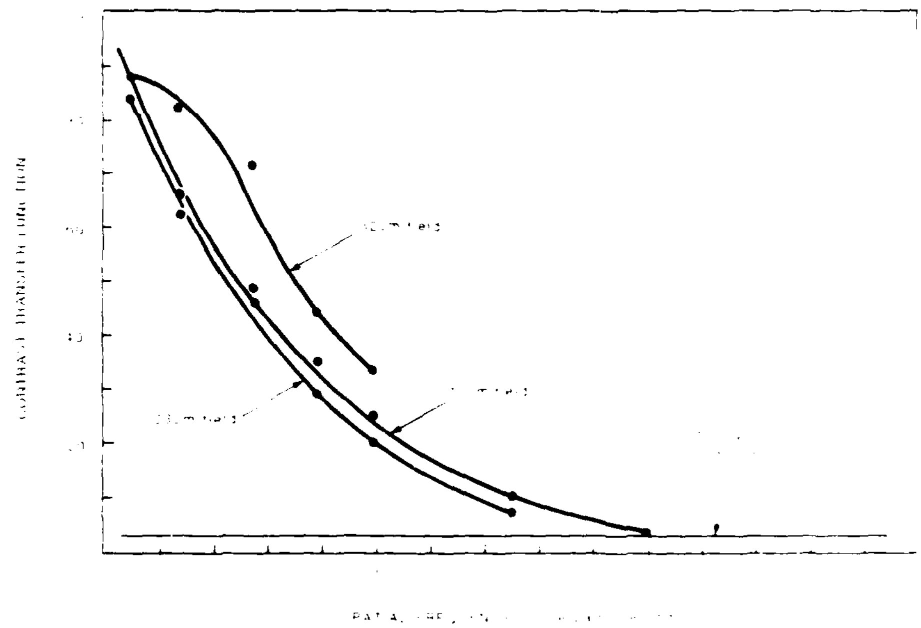


FIGURE 5D Contrast Transfer Function of System IV.

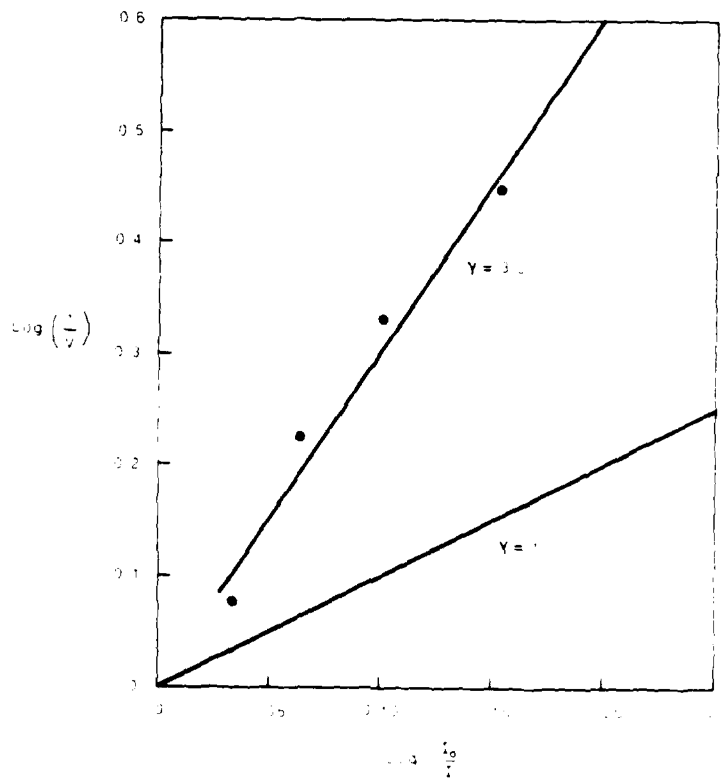


FIGURE 6 A log-log plot of normalised X-ray intensity against video voltage for System I. A plot of $\gamma = 1$ is shown for comparison.

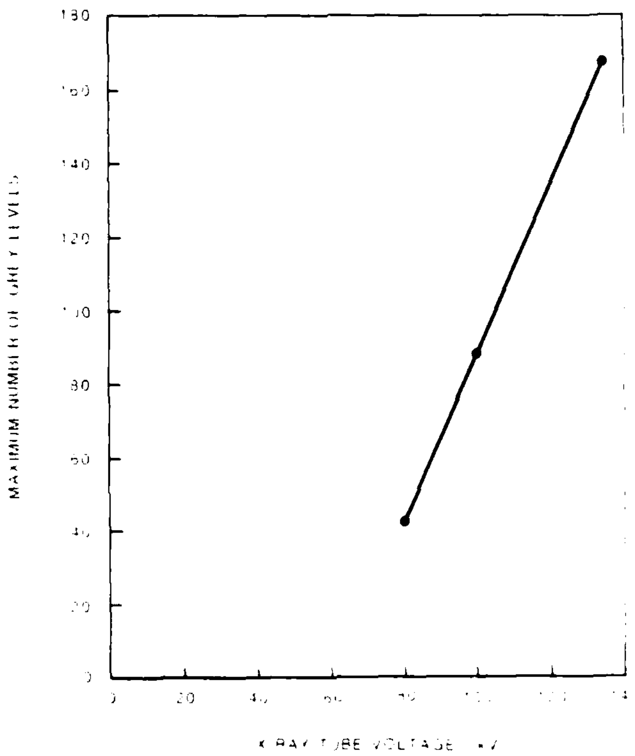


FIGURE 7 Variation of the number of grey levels in a digitized radiographic image with X-ray Tube Voltage.

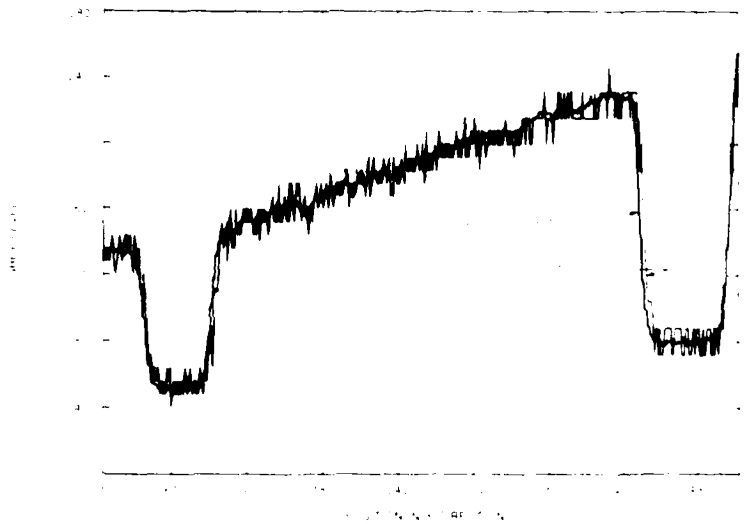


FIGURE 8 Variation in intensity across a fuze for two different integration levels.

APPENDIX A

There are several image transformations made in the real-time radiographic system shown in Figure 1. The geometry of the X-ray source, object and intensifier determines the X-ray image projected onto the input screen of the image intensifier. The X-ray image intensifier converts the X-ray image to a light image. This image is collimated by a separate lens, focal length f_c and magnified by the zoom lens, focal length f_z, to be projected onto the photo sensitive input screen of the television camera tube. This image is scanned by the tube's electron beam and reproduced by electronic means on a television monitor. The number of lines used in the scan vary with National standards and with tube type. Because of necessary electronic compensations within the television tube, only about 75% of these lines corresponding to maximum resolution are expected to be accurately reproduced [9]. The band width of the video amplifier is such that the horizontal resolution is at least equal to the number of vertical raster lines of the television tube.

For a radiographic system (Figure 1) of X-ray magnification M_X, image intensifier magnification M_I, lens magnification $M_L = f_z/f_c$, a television system aspect ratio 4:3, camera tube diameter D mm and F television lines, the horizontal resolution equals the vertical resolution and is given by:

$$\text{Resolution} = \frac{0.8\ D}{M_L M_I M_X F} \text{ mm per television line}$$

Similarly, for 1:1 aspect ratio system, the equations become:

$$\text{Vertical resolution} = \frac{4.0D}{3\sqrt{2}FM_L M_I M_X} \text{ mm per television line,}$$

$$\text{Horizontal resolution} = \frac{1.0\ D}{\sqrt{2}FM_L M_I M_X} \text{ mm per television line}$$

For the radiographic system with aspect ratio 4:3, and $M_X = 1.5$, $M_I = 1/6$, $M_L = 1.45$, ($f_c = 72.4$ mm, $f_z = 104.9$ mm), F = 500 lines, D = 25 mm, the vertical and horizontal resolutions are 0.11 mm/line.

APPENDIX B

Specifications of Equipment used in the Real-time Radiographic Systems

1. X-ray Tubes

Nominal Voltage	160 kV
Focal Spot	0.4 mm x 0.4 mm
Continuously rated current	0.4 mm focus : 4 mA

Nominal Voltage		320 kV
Focal Spot		1.2 mm x 1.2 mm
Continuously rated current		1.2 mm focus : 4 mA
Voltage	Constant DC	

2. Image Intensifier Tubes

23 cm Tube

Operating Modes	1	2	3
Input Field Diameter (cm)	23	15	10
Typical Resolution (lp/cm)	42	50	53

32 cm Tube

Operating Modes	Normal	M1	M2
Input Field Diameter (cm)	32	23	17
Typical Resolution (lp/cm)	32	36	40

3. Optical Components

Focal length, collimating lens 23 cm Tube 72.4 mm

Zoom Lens Aperture Ratio/Focal Length 1:2.5/16-160 mm

80 mm Macro Lens with 70 mm extension tubes

4. Television Cameras

Tube Type	1" Chalnicon
Gamma	0.95
Signal to Noise Ratio	better than 40db p-p/rms

Tube Type	1" Plumbicon
Gamma	0.95
Signal Noise Ratio	better than 40 db p-p/rms

5. Television Monitor

Model	Electrochrome	
Type	Monochrome	EVM 1519 X

SECURITY CLASSIFICATION OF THIS PAGE **UNCLASSIFIED**

DOCUMENT CONTROL DATA SHEET

REPORT NO	AR NO	REPORT SECURITY CLASSIFICATION
MRL-R-1068	AR-005-148	Unclassified

TITLE

Performance of a digital real time radiographic imaging system

AUTHOR(S)

M.J. Chung

CORPORATE AUTHOR

Materials Research Laboratories
PO Box 50,
Ascot Vale, Victoria 3032

REPORT DATE	TASK NO	SPONSOR
June 1987	ODP 84/091	Office of Defence Production

FILE NO	REFERENCES	PAGES
G6/4/8-3298	9	25

CLASSIFICATION/LIMITATION REVIEW DATE	CLASSIFICATION/RELEASE AUTHORITY
June 1990	Superintendent, MRL Physics Division

SECONDARY DISTRIBUTION

Approved for Public Release

ANNOUNCEMENT

Announcement of this report is unlimited.

KEYWORDS

Radiography
Radiographic Imaging
Munitions Inspection
Imaging techniques

SUBJECT GROUPS 0094J 0082B

ABSTRACT

This report examines the radiographic and electro-optical characteristics of a digital, real-time radiographic imaging system. It was found that;

a. for optimum X-ray magnifications the television camera tube in the system has a significant effect on image quality and

b. large variations in X-ray tube voltage may be tolerated before image degradation prevents successful computer image processing.

This work forms part of a study on a computer-aided inspection process.

SECURITY CLASSIFICATION OF THIS PAGE

UNCLASSIFIED

END

DATE

FILMED

2 88

DTIC